The leakage resistance to ground of a NIST Programmable Josephson Voltage Standard

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***Abstract* — The Programmable Josephson Voltage Standard (PJVS) leakage resistance to ground (LRG) is defined as the electrical resistance of one side of the measurement leads to ground. Under certain measurement conditions, this resistance can produce a significant systematic voltage error of the measured value of the PJVS output voltage. In particular, if the low side of the array is grounded, for instance in a direct comparison measurement with another JVS, then the LRG will reduce the PJVS output voltage. At 10 V, an error of 0.5 nV can result from a LRG of 50 GΩ if the measurement leads have a total resistance of 2.5 Ω. The LRG and the path of the leakage current to ground are difficult to determine. Furthermore, its corresponding voltage error is still present while the bias source is in operation to control the PJVS. It is therefore important to apply different measurement techniques to compare the corresponding LRG values.**

***Index Terms* — Leakage resistance to ground, Isolation resistance, Primary Voltage Standard, Josephson Voltage Standard, 10 V programmable array of Josephson junctions.**

I. Introduction

Following the successful implementation of Programmable Josephson Voltage Standards at 10 V [1,2], it is foreseeable that systems based on stable quantum voltage steps will in the future progressively replace the conventional Josephson voltage standard (CJVS) systems based on metastable, zero-crossing quantum voltage steps. PJVS systems have the potential to bring to the field of voltage metrology accuracy equivalent to CJVS, improved ease of use, and new measurement capabilities that exploit the intrinsic stability and programmability of their voltages. However, a number of precautions need to be followed in order to limit the magnitude of errors at the output of the probe [3].

The dominant precaution arises from a PJVS leakage resistance to ground (LRG) that is typically lower than that of the CJVS, which is defined as the electrical resistance of one side of the measurement leads to ground. The corresponding voltage error is detectable especially through direct comparisons of two JVS where relative voltage differences of better than 10^{-10} are measured. In the following, we present four different measurement techniques to measure the LRG of a PJVS and compare the results. Some of the components known to critically contribute to the LRG of the primary voltage standard are investigated.

II. PJVS Leakage Resistance to Ground (LRG)

The path of the leakage current to ground of a PJVS is very difficult to determine. On first approximation, the lowest resistance to ground will contribute to the total path of the current to ground. In the case of a PJVS, the path to ground through the current bias source and its dedicated power supply has to be taken into account.

We measured the resistance leakage to ground of the PJVS system using four different measurement setups in order to compare their results and associated uncertainty.

A. Direct measurement

The direct measurement method is based on the operation of a portable Keithley 500 megaohmeter. This instrument is portable, biased from a battery and offers the possibility of an internal adjustment of its scale before every measurement. This instrument has been operated for years on the BIPM transportable JVS [4], on which it has produced reproducible measurements.

B. BIPM measurement setup

A resistance r of 1 kΩ is connected to one side of the array and to ground (Fig. 1). The other side of the array, at a potential U, is left open so that the only path to ground is through one of the leakage resistances R_i, where R_i represents both the isolation resistance of the measurement leads (RL_i) and also the leakage to ground of the bias source through the DAC voltage cards and the amplifier board power supply (RB_i). RD_i correspond to the leakage resistances to ground of the detector and r_m to the resistance of either lead of the twisted-pair wires of the voltage output.

A nanovoltmeter is the detector that measures the voltage-time dependence across the resistor r, while the output voltage of the PJVS alternately switches from $+U$ to $-U$ and from $-U$ to $+U$. An example of the recorded V(t) for each polarity is presented in Fig. 2.

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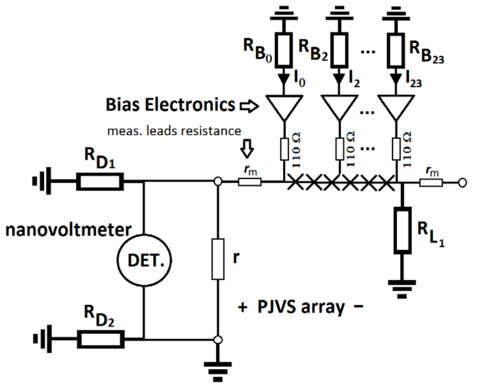

Fig. 1: Schematic of the experiment which allows the determination of the leakage resistance to ground of the PJVS.

The shapes of the curves are the result of a dielectric absorption in the circuit. At a typical time of 15 s to 20 s after a polarity reversal, the leakage current reaches an asymptotic value corresponding to the apparent leakage resistance to ground of the PJVS (Fig. 2).

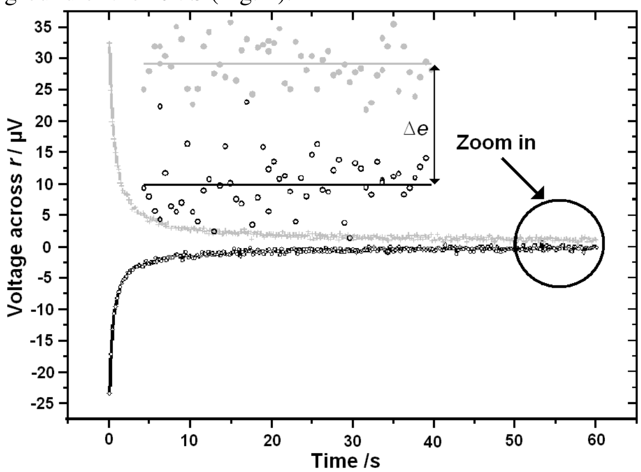

Fig. 2: Measured voltage across the 1 kΩ resistance *r* when switching from positive polarity (+10 V) to negative polarity (-10 V) (black) and switching from negative to positive (grey). Inset shows a zoom of the last five seconds of both data. The lines represent the average of the points and their difference is defined as $\Delta e = i_L \times r$ and R_i.=10 / i_L.

This LRG measurement method has the advantage of using the output voltage of the PJVS to perform the experiment and therefore is closer to the operating configuration of the PJVS. The method can easily be implemented as part of the NIST software, *NIST-Core* [4], for the PJVS operation.

C. Battery source measurement setup

The principle of the second experiment is equivalent to the BIPM measurement setup with the exception that the test voltage, *U*, is provided by a battery [3]. In this measurement configuration, the probe and array are removed from the measurement setup with the goal to evaluate the LRG contribution of the PJVS bias circuit. The results show that even if the leakage resistance of the PJVS bias circuit strongly depends on the type of power supply, there might be other components of the PJVS, like the DAC cards of the bias source that may contribute to lower its resistance to ground.

D. Line resistance insertion in a direct comparison

The last investigation is based on a direct JVS comparison setup, where the first primary voltage standard is the BIPM CJVS transportable system [5]. This system is directly compared at 10 V to the NIST PJVS. The voltage error arising from the leakage resistance of the CJVS can be minimized because of its excellent voltage stability in time after the bias source is physically disconnected from the array. In this setup, a variable line resistance is inserted between the two positive poles of the two primary voltage sources. The corresponding leakage current changes linearly with the voltage difference between the two standards. From the results, the leakage current and corresponding LRG at 10 V can be deduced [6-7]. All the results will be presented in detail during the conference.

VI. Conclusion

It is difficult to evaluate the leakage resistance to ground of a complete PJVS system and an associated measurement setup, because the LRG can arise from different components of the PJVS bias circuit as well as the output leads. Furthermore, the value of the calculated leakage resistance strongly depends on the choice of several parameters, such as the total time of the recordings and the time interval selected for the final calculation. Finally, the experiment is very sensitive to the electromagnetic environment and, in particular, the electrostatic component that will directly affect the voltage readings based on the immunity of the DVM to EMI. It is essential to evaluate the LRG since it can produce a voltage error up to a few nanovolts that will contribute a systematic error in the measurement configuration where a PJVS is directly compared to one another JVS.

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